

10 35
049 903

NASA Grant NAG5-4445
Photon-weighted Midpoint Exposure Meter for
Keck/HIRES Extrasolar Planet Research
2nd year Progress Report
Prepared: April 22, 1999

1 INTRODUCTION

NASA Grant NAG5-4445 was received on May 1, 1997 for research involving the construction of a photon-weighting midpoint exposure meter for the Keck HIRES spectrometer, and for support of our NASA/Keck-based planet research with this instrumentation. The research funds were also to be used to make our iodine cell calibration system and exposure meter available to the NASA Keck observing community. Progress this past year, the second of the 3-year granting period, involved work in 4 areas:

- 1) Further construction of the midpoint exposure meter.
- 2) Assisting observers with use of the Iodine system.
- 3) Acquisition of precision radial velocity data on our program star sample with continued monitoring to proceed in subsequent years as available telescope time permits.
- 4) Reduction and analysis of incoming precision radial velocity data to reject problematic and uninteresting program stars, and to identify promising planet candidates.

2 PERSONNEL

Personnel on this grant are Drs. Geoffrey W. Marcy, R. Paul Butler, and Steven S. Vogt. Dr. Marcy is a Distinguished University Professor at San Francisco State and Adjunct Professor at U.C. Berkeley. Dr. Butler is a Research Scientist at the Anglo-Australian Observatory in Epping, Australia. Dr. Vogt is a Professor/Astronomer at UCO/Lick Observatory.

3 PROGRESS DURING THE SECOND YEAR

3.1 Exposure Meter Design and Construction

The Mid-point exposure meter is still in the construction phase at the UCO/Lick Observatory Labs in Santa Cruz. Work on this project has been halted for at least the past 8 months due to heavy pressure at the shops to finish other instruments for Keck. Thus, the exposure meter project has essentially been placed on hold in the labs. The mechanical work is completely finished, and the electrical work is also essentially done. Remaining work is the software graphical user's interface, and installation/commissioning at Keck.

As P.I. of this grant, I must say that I am totally frustrated by the UCO/Lick Labs inability over the past year, to give this project any priority. But at present, I can only sit back and wait, until other higher-priority Keck instruments backlogging the Labs are completed, and manpower

opens up for completing the HIRES exposure meter.

As regards the impact of not having a mid-point exposure meter on our extrasolar planet search, several years ago, we made changes in our observing strategy to lessen the impact of the late arrival of this piece of equipment on our survey. In particular, we have been keeping all of our exposure times on program objects to less than 10 minutes, to avoid introducing excessive errors in the midpoint times of each exposure, which can introduce radial velocity errors at the several meters/sec level. Since most of our objects can be reached with 10-minute exposures, this has had very little impact on our observing strategy. Fainter objects requiring longer exposures could also be done with multiple 10-minute exposures. The exposure meter would also help us maximize observing efficiency by stopping each exposure at a precise S/N. To work around this, we have simply been computing 'expected' exposure times for each program object to achieve a set S/N level. We then monitor deviations from these 'expected' exposure times as each night proceeds, and apply hourly corrections throughout the night to maintain a roughly constant S/N for each radial velocity observation.

3.2 Assisting User's of the Iodine Cell System

A goal of this proposal was to document our proprietary iodine cell precision radial velocity system and make it available for use by the general NASA/Keck observing community. The documentation was done the first year. This past year, we have continued to help scheduled Keck observers with the proper use of the Iodine cell system. Observers from four different planet-search groups (Latham, Noyes, Cochran, Lissauer) have each spent several nights watching as we observed with the iodine cell, and learning our observing techniques. These four groups are now involved in their own independent planet search programs, using the Keck/Hires facility.

3.4 Data Acquisition

We presently have about 450 stars on the Keck program, distributed fairly evenly in RA across the sky. This past year (since 5/1/98) we were fortunate to have receive a total of 30 nights of time on Keck I with HIRES. This allocation was a combination of both NASA/Keck and UC/Keck time allocations. On our longest (winter) nights, we typically observe about 100 stars/night, while on the shortest (summer) nights, we typically hit about 65. All spectra are reduced, and all Doppler measurements are finished, including the most recent observing run that concluded Feb. 19, 1999. We been able now to categorize many of our program stars into one of three classes and thereby decide the optimum observing strategy for following years:

1. No Variation: Observe only once per year
2. Slow variation: Observe twice per year
3. Rapid variation: Observe every available night

3.5 Data Reduction

Data reduction commences at the end of each night's observing. Midpoint exposure times are calculated and logged as each spectrum is obtained throughout the evening. In the morning before retiring, barycentric corrections are calculated and the stellar spectra are extracted from the echelle format and ftp'd to Berkeley for radial velocity processing. Fully reduced radial velocities are generally available within 2-3 days of each run. The reduced data are archived and the raw spectral data are available to the general public upon request.

3.6 Keck Planet Detection Results

During the past year using HIRES and Keck, we have published four new extrasolar planet candidates, namely around Gliese 876, HD 187123, HD 210277, and HD 168443 (see Figure 1). All four have $M \sin i < 5 M_{\text{JUP}}$. These Keck planet discoveries bring the total number of detected planets now to about 17.

The 17 known extrasolar planets exhibit two remarkable properties. First, the distribution of masses (Figure 2) shows that brown dwarfs are rare, occurring around less than 1% of main sequence stars. But for companions below $5 M_{\text{JUP}}$, the occurrence rises significantly. We find that the planet mass distribution rises sharply for masses below $\sim 5 M_{\text{JUP}}$ (Fig 2a).

The second unexpected property is the high occurrence of elliptical orbits (Fig. 2b). Among the 9 planets having semi-major axes, $a > 0.2 \text{ AU}$, *all 9 have eccentricities greater than 0.1*, rendering them more eccentric than any of the giant planets in our Solar System. These orbital eccentricities are consistent with standard planet formation in circumstellar disks, but followed by gravitational perturbations exerted by other planets, stars, or the protoplanetary disk (Rasio and Ford 1996, Weidenschilling and Marzari 1996, Lin et al. 1996, Levison et al. 1998).

In addition, there is an apparent "piling-up" of planets near their host stars. Our models of "ensembles" of planetary systems suggest that the presently large fraction of small orbits of Jupiters could be due to selection effects in the sample that renders close-in Jupiters more easily detectable. More planet detections are needed to establish the true distribution of orbital radii. Nonetheless, theories of the formation mechanisms, atmospheric structure, and orbital evolution of extrasolar planets are emerging from the planet detections (Boss 1997; Burrows et al. 1995, Lin et al. 1996, Lunine et al. 1997, Trilling et al. 1998).

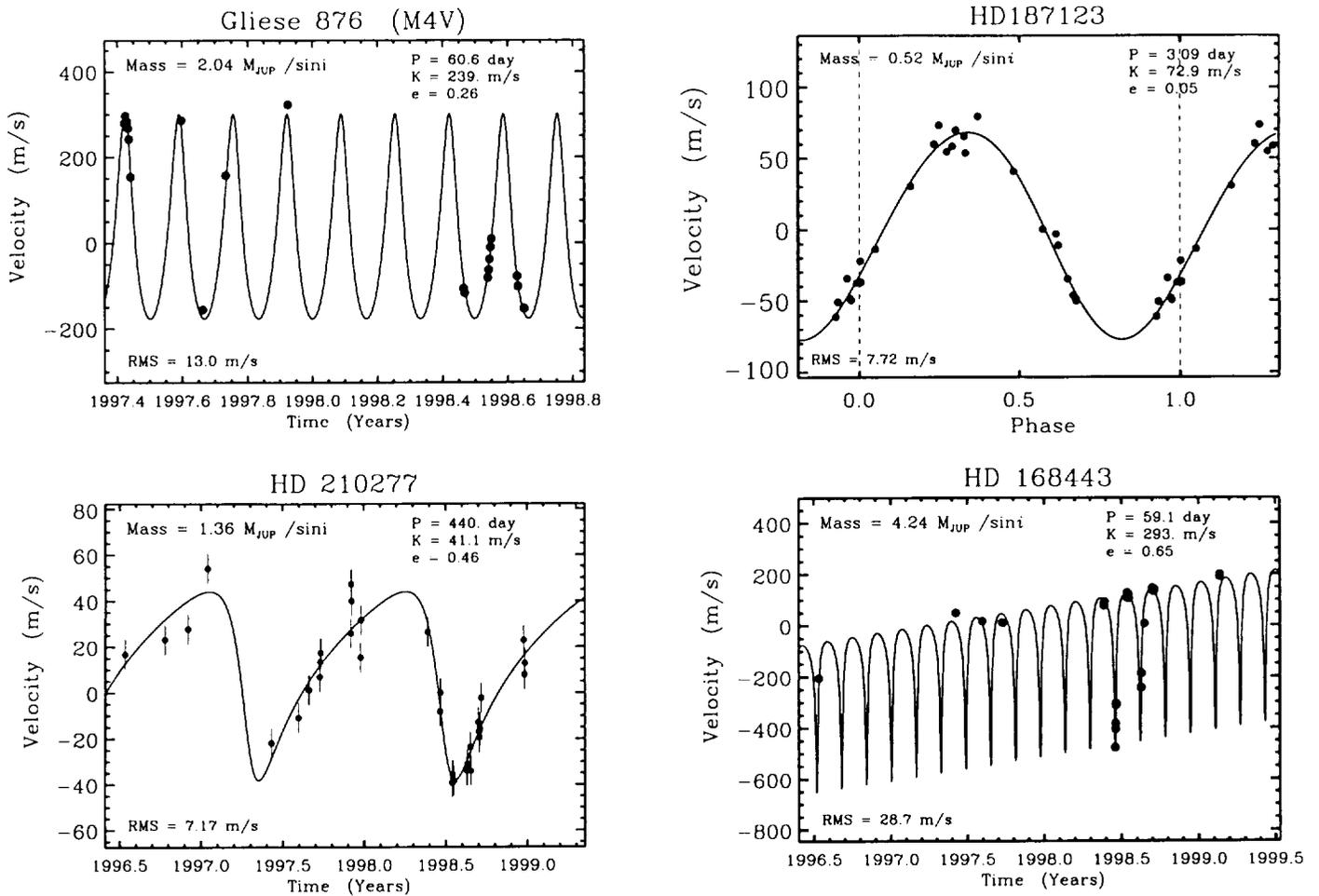


Fig. 1.— Four planet detections made from our Keck observations this past year. The planet candidate around HD 210277 has a period of 440 days, implying a semi-major axis of 1.1 AU. The velocities for HD 168443 (bottom right) show not only a planetary-mass companion, but also a superimposed trend due to some additional companion, requiring more data for elucidation.

5 PUBLICATIONS

1999, “Planetary Companions around Two Solar-Type Stars: HD 195019 and HD 217107” (D.A. Fischer, G.W. Marcy, R.P. Butler, S.S. Vogt, and K.Apps), P.A.S.P. 111, 50.

1998, “A Planet with a 3.1 Day Period around a Solar Twin”, (R.P. Butler, G.W. Marcy, S.S. Vogt, and K. Apps), P.A.S.P. 110, 1389.

1998, “Extrasolar Planets: Masses and Orbits”, (G.W. Marcy, R.P. Butler, S.S. Vogt, and D.A. Fischer), Bull. A.A.S., 193, 9703.

1998, “A Planetary Companion to a Nearby M4 Dwarf, Gliese 876”, (G.W. Marcy, R.P. Butler, S.S. Vogt, and D.A. Fischer, and J.J. Lissauer), ApJ., 505, L147.

1998, “The Keck Search for Extrasolar Planets”, (G.W. Marcy, R.P. Butler, S.S. Vogt, and P.

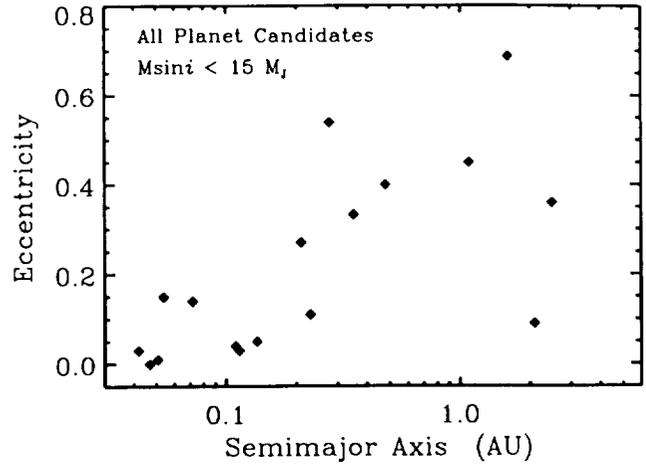
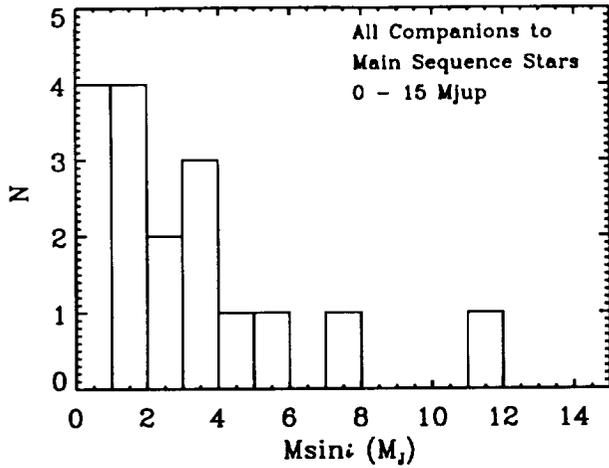


Fig. 2.— **Left:** The histogram of $M \sin i$ for all known 17 known planet candidates, 12 found by our group. **Right:** Orbital eccentricity vs. Semi-major Axis, showing that all 9 planets which orbit beyond 0.2 AU reside in eccentric orbits.

Shirts), *Bull. A.A.S.*, 192, 0801

1998 “Searches for Planetary Companions with Lick, Keck, and AAT” (G. W. Marcy, R.P. Butler, and S.S. Vogt), *IAU Colloq. 170 Precise Stellar Radial Velocities*, Victoria, British Columbia, June 21-26, 1998.

1998 “Detections of Extrasolar Giant Planets”, in *Annual Reviews of Astronomy and Astrophysics*, ed. G. Burbidge. (Marcy and Butler)

1998 “Extrasolar Planets: Back in Focus”, *Nature*, 39, 127. (Marcy)

1998, “New Worlds: The Diversity of Planetary Systems”, (G.W. Marcy, and R.P. Butler), *Sky and Telescope*, 95, 30.

1998 “Giant Planets Orbiting Faraway Stars”, in *Scientific American Presents*, Vol. 9, Num.1, March 1998 issue, p10. (Marcy and Butler)

file: PAPERS/PROPOSALS/1996/NASA/secondreport.tex